Briefing to the ESSAAC
Technology Subcommittee (TSC)

on

Passive Microwave (Radiometer) Electronics Technology Requirements & Roadmaps

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Outline

- ✓Process followed by Working Group
- ➢ESTO focuses on TRL range 2-3 to 5-6
- ➢Passive microwave scenarios
- ➢Example measurement requirements
- ➢Technology challenge areas for passive electronics
  - •Overview
  - •Major groupings
  - •Histograms
  - •Overlaps with other subgroups
- ➢Prioritization recommendations
- ➢Integrated roadmap
- ➢Improvement suggestions

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Science Measurement Scenarios for Passive Remote Sensing

Measurement Parameters	Focus Science Areas	Measurement Scenarios
Snow Cover, Accumulation and Water (SWE, wetness)	Water & Energy Cycle; Weather; and Climate Variability & Change	106, 107, 108, H2, C2
Freeze/Thaw Transition (Growing Season)	Water & Energy Cycle; and Climate Variability & Change	H1
Soil Moisture	Water & Energy Cycle; Weather; and Climate Variability & Change	34, 38, 111, 177, H2, H3
Precipitation	Water & Energy Cycle and Weather	67, 176, A1,A2
Sea Surface Salinity	Climate Variability & Change	34, 38, 111
Sea Surface Temperature	Climate Variability & Change	O1
Atmospheric Temperature	Water & Energy Cycle and Weather	67, 176
Atmospheric Water Vapor	Water & Energy Cycle and Weather	67, 176
Ocean Surface Winds	Weather	A2
Ozone Profile	Atmospheric Composition	140
Cloud System Structure	Atmospheric Composition	143
Wet Path Delay	Solid Earth (Geodesy)	53

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Sample Radiometer Requirements Development

Measurement Parameter	Scenario ID	Sensor type	Sensor Description	Electronics Technology Requirements	Comments
			Hydrology		
Snow cover, accumulation, and water equivalent (i.e, SWE & wetness)	C2	Synthetic Thinned Array Radiometer (STAR)	STAR imager with no moving parts which images via software beam forming. Wide swath, ~5 km spatial resolution at 19 and 37 GHz with dual linear polarizations.	Low power, microwave PLL Local Oscillators; Distributed correlated microwave noise sources.	Enabling Technology (ESTO Technology Planning Workshop 2003, panel D; revised by ESTO Radar/Radiometer Working Group 2003)
Soil moisture,Sea surface salinity	38	Large Real Aperture Antenna Radiometer and Scatterometer	Rotating ~25-m diameter antenna with 10-km resolution in a conical scan. Alternatively, a parabolic torus containing a push-broom focal plane array with > 100 elements eliminates the need to rotate the system. 1.4 GHz polarimetric radiometers with a stability of 0.1 K over periods of 2-5 days. 3rd Stokes …to correct for the ionosphere. 1.2 GHz radar to provide roughness correction.	Low power MMIC "radiometers-on-a-chip"; Ultra-stable radiometers with receiver stability ~0.1K over several days; Analog RFI mitigation; combined active-passive system design	Enhancing Technology (for Electronics) (ESTO Technology Planning Workshop 2003, panel D; revised by ESTO Radar/Radiometer Working Group 2003.)

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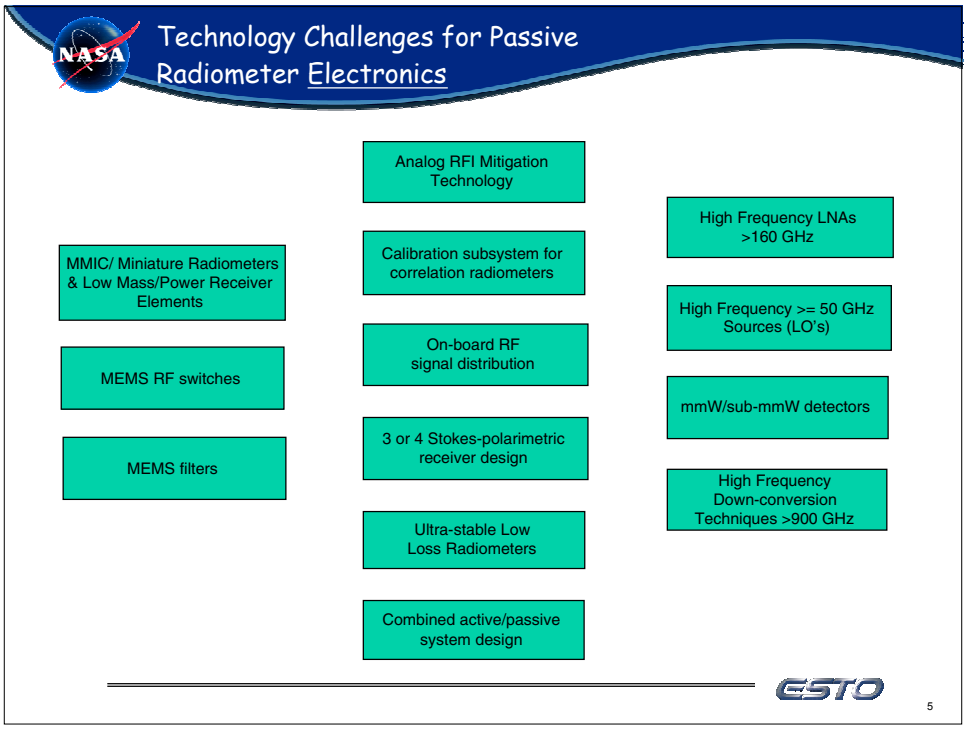
Technology Challenges for Passive Radiometer Electronics
Analog RFI Mitigation Technology
Calibration subsystem for correlation radiometers
On-board RF signal distribution
3 or 4 Stokes-polarimetric receiver design
Ultra-stable Low Loss Radiometers
Combined active/passive system design
MMIC/ Miniature Radiometers & Low Mass/Power Receiver Elements
MEMS RF switches
MEMS filters
High Frequency LNAs >160 GHz
High Frequency >= 50 GHz Sources (LO's)
mmW/sub-mmW detectors
High Frequency Down-conversion Techniques >900 GHz
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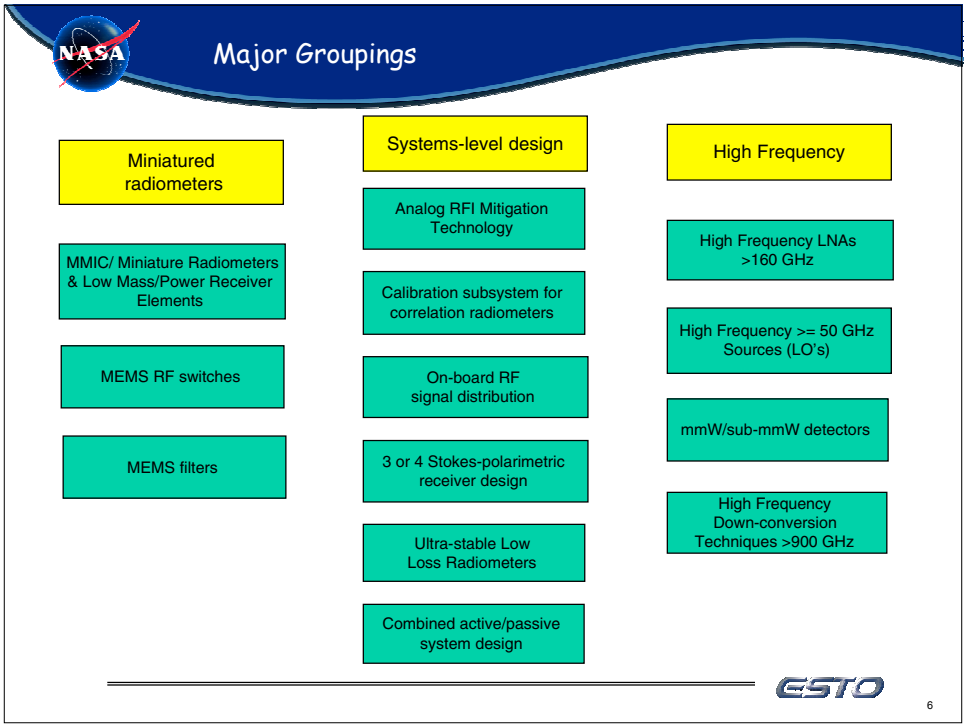
Major Groupings
Systems-level design
Analog RFI Mitigation Technology
Calibration subsystem for correlation radiometers
On-board RF signal distribution
3 or 4 Stokes-polarimetric receiver design
Ultra-stable Low Loss Radiometers
Combined active/passive system design
Miniatured radiometers
MMIC/ Miniature Radiometers & Low Mass/Power Receiver Elements
MEMS RF switches
MEMS filters
High Frequency
High Frequency LNAs >160 GHz
High Frequency >= 50 GHz Sources (LO's)
mmW/sub-mmW detectors
High Frequency Down-conversion Techniques >900 GHz
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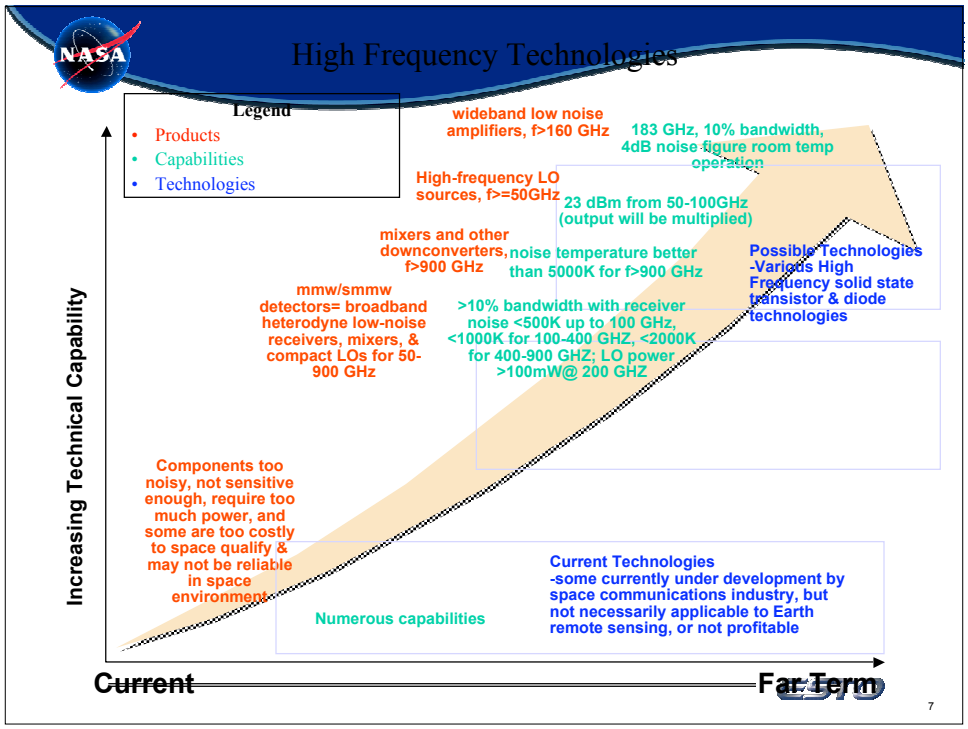
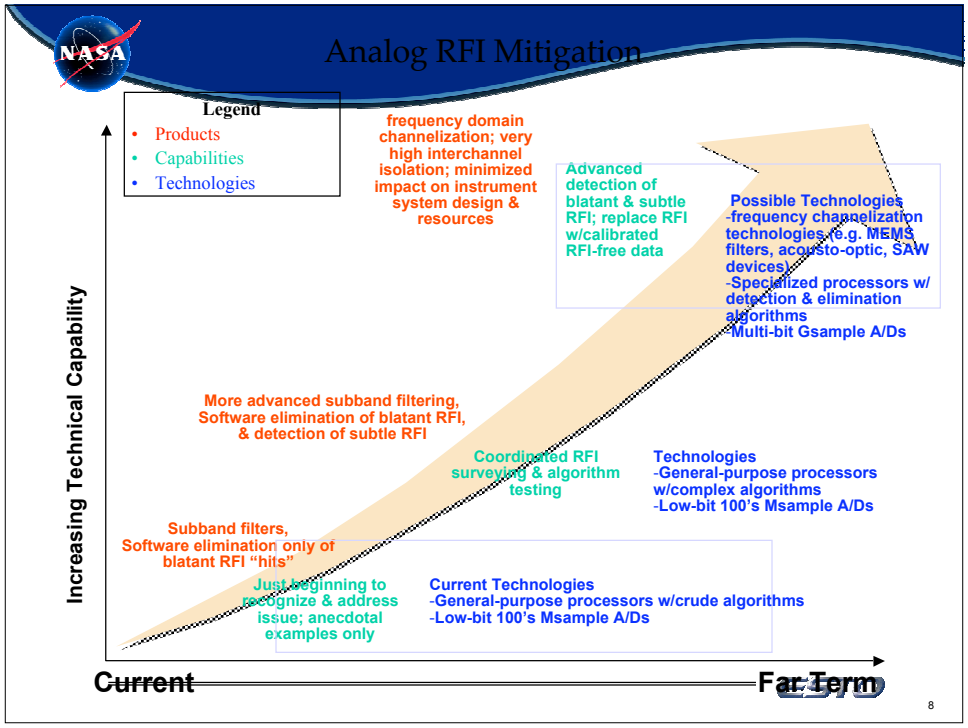

High Frequency Technologies
Legend
• Products
• Capabilities
• Technologies
wideband low noise amplifiers, f>160 GHz
183 GHz, 10% bandwidth, 4dB noise figure room temp operation
High-frequency LO sources, f>=50GHz
23 dBm from 50-100GHz (output will be multiplied)
mixers and other downconverters, f>900 GHz
noise temperature better than 5000K for f>900 GHz
Possible Technologies -Various High Frequency solid state transistor & diode technologies
mmw/smmw detectors= broadband heterodyne low-noise receivers, mixers, & compact LOs for 50-900 GHz
>10% bandwidth with receiver noise <500K up to 100 GHz, <1000K for 100-400 GHZ, <2000K for 400-900 GHZ; LO power >100mW@ 200 GHZ
Components too noisy, not sensitive enough, require too much power, and some are too costly to space qualify & may not be reliable in space environment
Numerous capabilities
Current Technologies -some currently under development by space communications industry, but not necessarily applicable to Earth remote sensing, or not profitable
Increasing Technical Capability
Current
Far Term
7


Analog RFI Mitigation
Legend
• Products
• Capabilities
• Technologies
frequency domain channelization; very high interchannel isolation; minimized impact on instrument system design & resources
Advanced detection of blatant & subtle RFI; replace RFI w/calibrated RFI-free data
Possible Technologies -frequency channelization technologies (e.g. MEMS filters, acousto-optic, SAW devices) -Specialized processors w/ detection & elimination algorithms -Multi-bit Gsample A/Ds
More advanced subband filtering, Software elimination of blatant RFI, & detection of subtle RFI
Coordinated RFI surveying & algorithm testing
Technologies -General-purpose processors w/complex algorithms -Low-bit 100's Msample A/Ds
Subband filters, Software elimination only of blatant RFI "hits"
Just beginning to recognize & address issue; anecdotal examples only
Current Technologies -General-purpose processors w/crude algorithms -Low-bit 100's Msample A/Ds
Increasing Technical Capability
Current
Far Term
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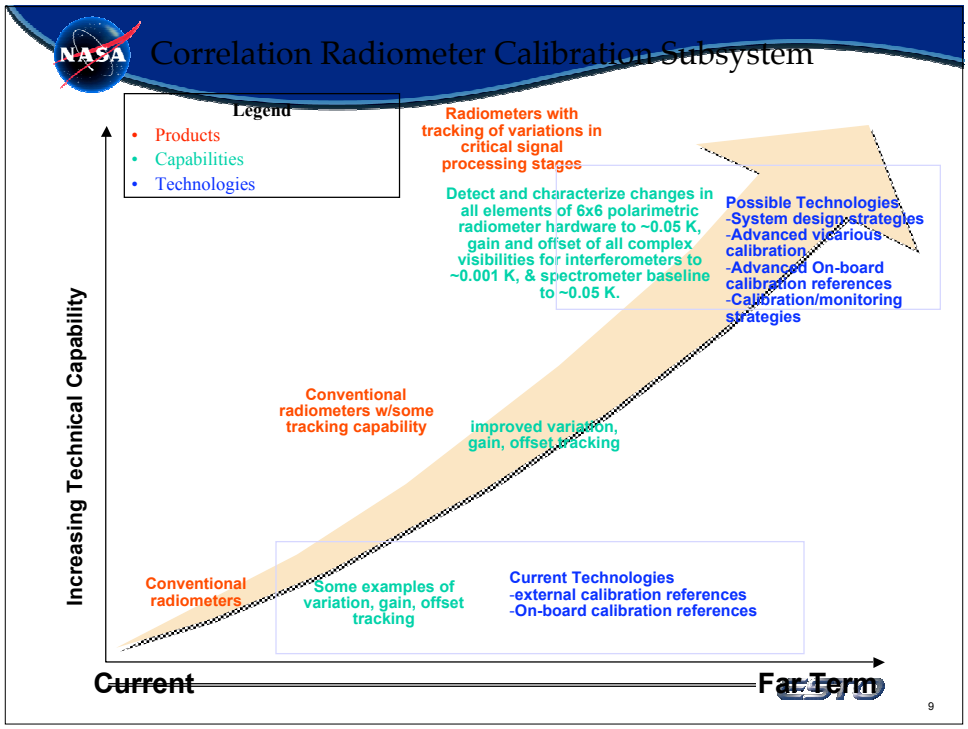

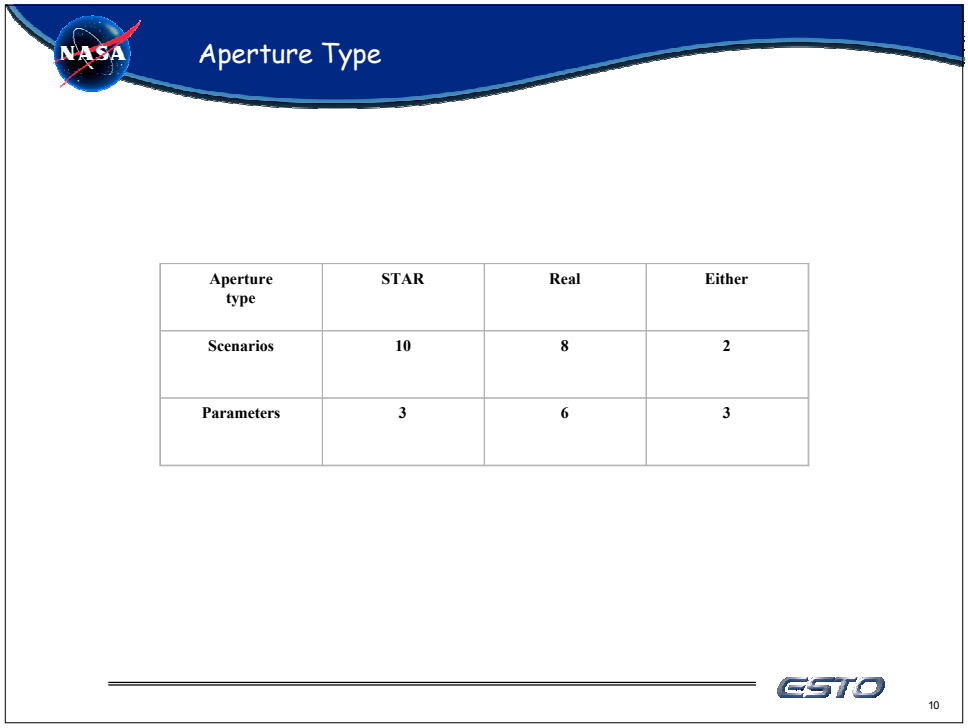

Aperture type	STAR	Real	Either
Scenarios	10	8	2
Parameters	3	6	3

Platforms/Orbits

Platform	LEO	MEO	GEO	UAV	Ground
Scenarios	16	0	2	2	1
Parameters	9	0	3	2	1

•Note that two scenarios (A1 and A2) list both UAV and spaceborne LEO orbits as platform options.

•Some precipitation scenarios call for LEO while others call for GEO.

•LEO applies to the greatest number of measurement scenarios combining improved resolution from larger apertures with the lower range of operating frequencies. This represents a desire for finer spatial resolutions attainable with larger apertures in lower orbits while subject to limitations on overall package size.

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Frequency Bands

Frequency Band	L	C	X	Ku (18)	K (21)	Ka	V (50)	W	100-300 GHz	300-1000 GHz	>1 THz
Scenarios	10	5	5	6	1	7	2	3	4	2	2
Parameters	4	4	5	2	1	3	3	1	5	2	2

Overall the 1 to100-GHz frequency range covers most of the interest and is the range over which the majority of microwave-water cycle interactions occur (soil moisture, salinity, snow, freeze/thaw, sea ice, precipitation).

Frequencies above 100 GHz generally have specific applications, primarily atmospheric composition and clouds representing a more specialized subset of the measurement scenarios.

Significant RFI is observed at L & C bands. RFI mitigation is needed immediately.

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Polarizations

# of Pols	1-2	>=3	4
Scenarios	11	8	2
Parameters	11	6	2

• 1-2 pols: no ionospheric propagation considerations or 2D-STAR polarization separation considerations

• >=3 Stokes' parameters: either
  •(a) real-aperture or 1D-STAR and ionospheric correction is required or
  •(b) 2D-STAR and polarization separation might be needed.

• 4 Stokes' parameters: 2D-STAR when polarization separation is definitely needed.

Note: Some scenarios involve combinations of low frequencies (with ionospheric considerations) and higher frequencies (no ionospheric correction needed), resulting in certain measurement scenarios appearing in more than one category.

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Combined Passive/Active Instruments

Potential	Yes	Possibly	No (Passive Only)
Scenarios	5	4	10
Parameters	3	2	7

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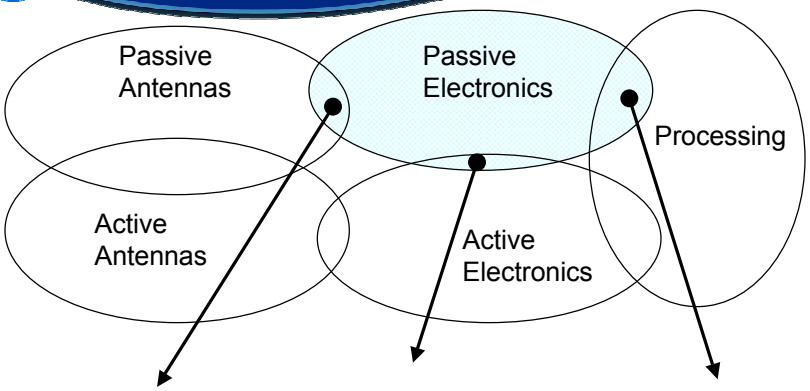
Technology Challenges – Overlaps



- Calibration
- RFI mitigation
- MEMS

- MMIC/miniature modules
- MEMS
- Digital receivers
- Signal distribution
- Thermal mgmt

- ADC interface & coordinated receiver/backend design
- Calibration
- RFI mitigation
- STAR processing/correlators
- Ionospheric compensation

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Technology Challenges – Recommendations

Highest return:
MMIC/ Miniature+ Low Mass/Power Radiometers, MEMS filters and RF switches, analog RFI Mitigation Technology

Next highest return:
Calibration subsystem for correlation radiometers, on-board RF signal distribution, combined active/passive system design, 3&4-Stokes polarimetric receiver design, ultrastable low loss radiometers.

Medium/Lower return:
High frequency LNAs > 160 GHz, LO sources >50 GHz, down-conversion techniques >900 GHz, and mmW/smmW detectors.

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Technology Challenges – Recommendations

Technology Challenge		scenarios max =19	parameters max =12
High Frequency Radiometer Electronics			
High Frequency LNAs >160 GHz		5	5
High Frequency >= 50 GHz Sources (LO)		6	6
MMW/sMMW detectors		6	6
High Frequency Downconversion Techniques >900 GHz	2	2	
Miniature Radiometer Electronics			
MMIC/ Miniature Radiometers & Low Mass/Power Receiver Elements		16	11
MEMS RF switches		14	10
MEMS filters		14	10
Systems-level Radiometer Design Technologies			
Analog RFI Mitigation Technology		15	8
Calibration subsystem for correlation radiometers		13	6
On-board RF signal distribution		13	9
3 or 4 Stokes-polarimetric receiver design		10	8
Ultrastable Low Loss Radiometers		11	6
Combined active/passive system design		9	5

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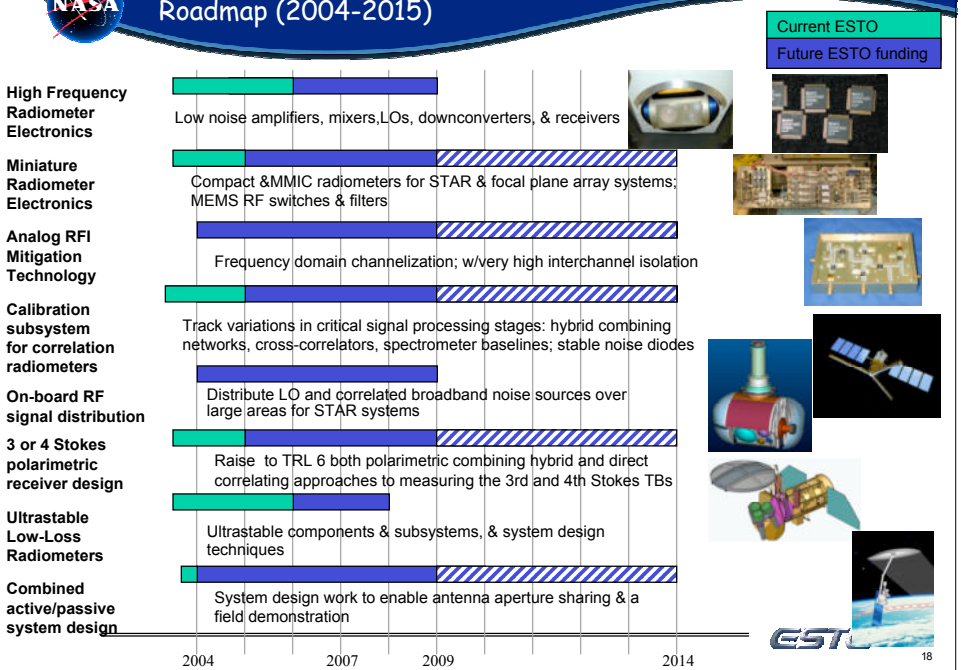
Passive Electronics Technology Integrated Roadmap (2004-2015)



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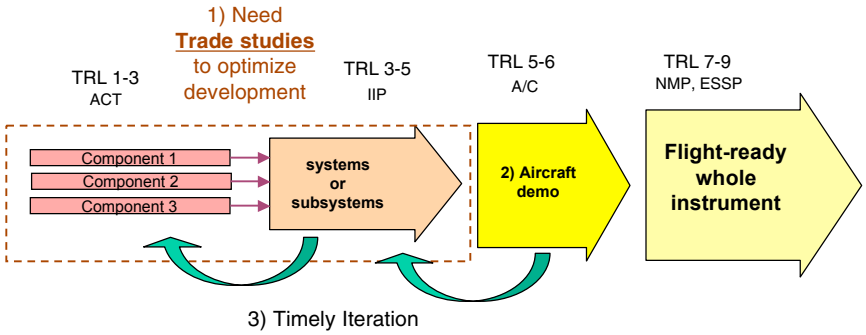
Improvements

- ESTO is Code Y's primary technology development mechanism
- ESTO programs span TRL 2-3 up to TRL 5 (& sometimes 6)
- Spaceflight programs span TRL 7-9
- There are 3 improvement areas:



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BACK-UP SLIDES

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Academia ,Industry, & Other Gov't Labs

Representative listing of academic and industry participation/collaborations

- MEMS: Darpa (extensive program)
- MMICs/miniature receivers: TRW, Hughes, & a *large* number of other companies
- 3-4 Stokes radiometer design: NRL, ETL, Umass, U.Michigan
- Calibration for correlation radiometers: U.Michigan, EMAG, NRL, ETL

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Technology Challenges -

charts of individual technology areas

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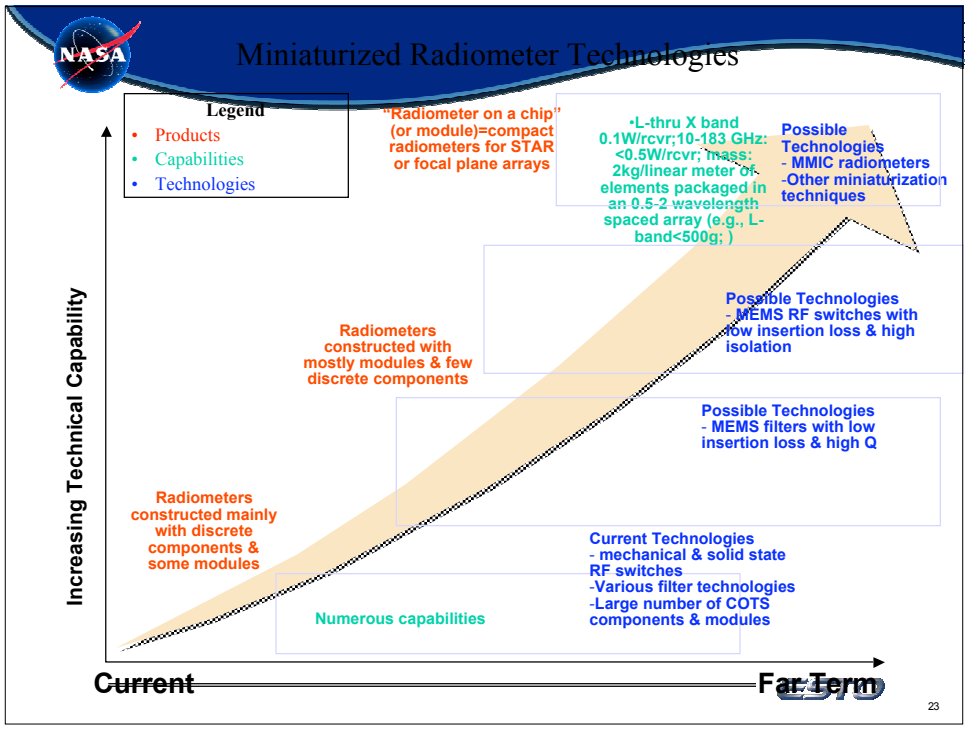
Miniaturized Radiometer Technologies
Legend
• Products
• Capabilities
• Technologies
"Radiometer on a chip" (or module)=compact radiometers for STAR or focal plane arrays
•L-thru X band 0.1W/rcvr;10-183 GHz: <0.5W/rcvr; mass: 2kg/linear meter of elements packaged in an 0.5-2 wavelength spaced array (e.g., L-band<500g;)
Possible Technologies
- MMIC radiometers
-Other miniaturization techniques
Possible Technologies
- MEMS RF switches with low insertion loss & high isolation
Radiometers constructed with mostly modules & few discrete components
Possible Technologies
- MEMS filters with low insertion loss & high Q
Radiometers constructed mainly with discrete components & some modules
Current Technologies
- mechanical & solid state RF switches
-Various filter technologies
-Large number of COTS components & modules
Numerous capabilities
Increasing Technical Capability
Current
Far Term
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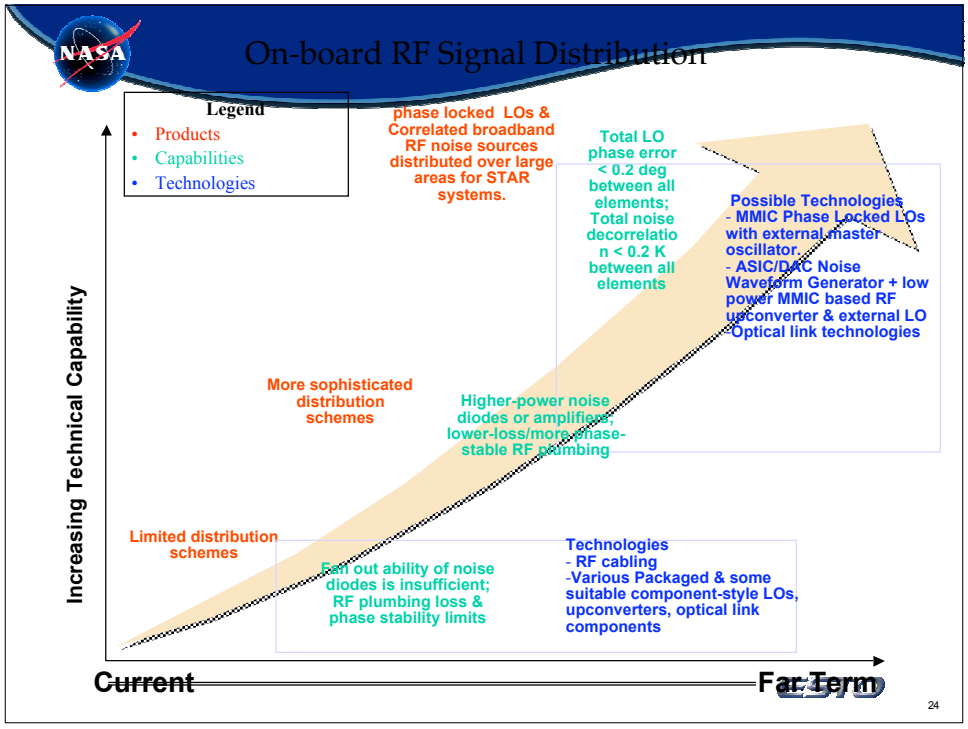
On-board RF Signal Distribution
Legend
• Products
• Capabilities
• Technologies
phase locked LOs & Correlated broadband RF noise sources distributed over large areas for STAR systems.
Total LO phase error < 0.2 deg between all elements; Total noise decorrelation < 0.2 K between all elements
Possible Technologies
- MMIC Phase Locked LOs with external master oscillator.
- ASIC/DAC Noise Waveform Generator + low power MMIC based RF upconverter & external LO
-Optical link technologies
More sophisticated distribution schemes
Higher-power noise diodes or amplifiers; lower-loss/more phase-stable RF plumbing
Limited distribution schemes
Fall out ability of noise diodes is insufficient; RF plumbing loss & phase stability limits
Technologies
- RF cabling
-Various Packaged & some suitable component-style LOs, upconverters, optical link components
Increasing Technical Capability
Current
Far Term
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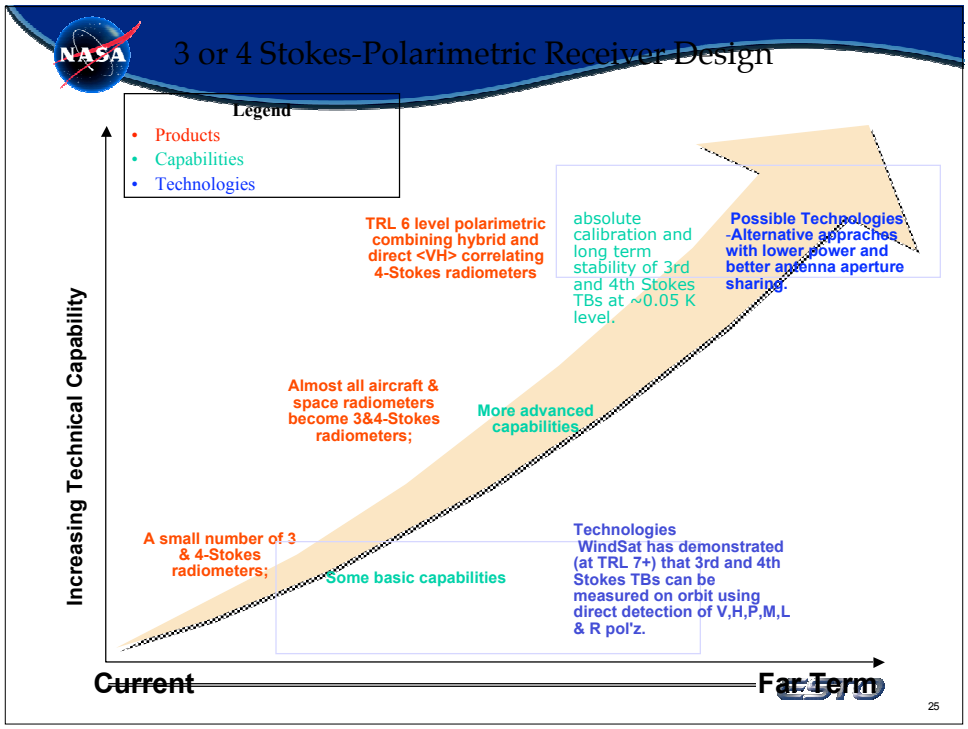
3 or 4 Stokes-Polarimetric Receiver Design
Legend
• Products
• Capabilities
• Technologies
TRL 6 level polarimetric combining hybrid and direct <VH> correlating 4-Stokes radiometers
absolute calibration and long term stability of 3rd and 4th Stokes TBs at ~0.05 K level.
Possible Technologies -Alternative approaches with lower power and better antenna aperture sharing.
Almost all aircraft & space radiometers become 3&4-Stokes radiometers;
More advanced capabilities
A small number of 3 & 4-Stokes radiometers;
Some basic capabilities
Technologies
WindSat has demonstrated (at TRL 7+) that 3rd and 4th Stokes TBs can be measured on orbit using direct detection of V,H,P,M,L & R pol'z.
Increasing Technical Capability
Current
Far Term
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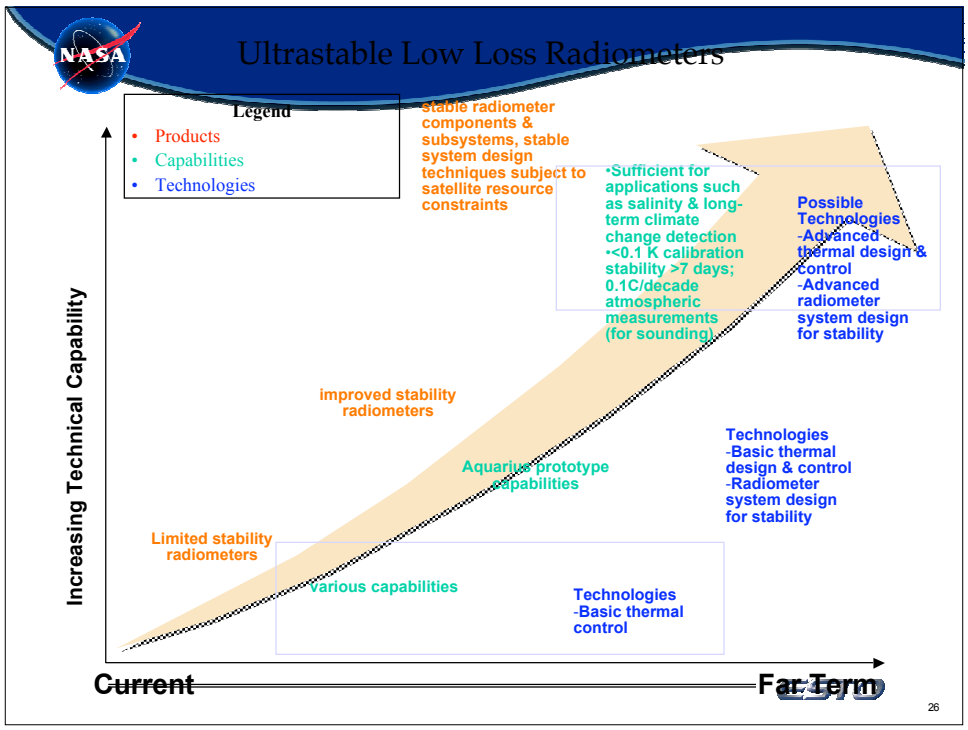
Ultrastable Low Loss Radiometers
Legend
• Products
• Capabilities
• Technologies
stable radiometer components & subsystems, stable system design techniques subject to satellite resource constraints
•Sufficient for applications such as salinity & long-term climate change detection
•<0.1 K calibration stability >7 days; 0.1C/decade atmospheric measurements (for sounding)
Possible Technologies -Advanced thermal design & control -Advanced radiometer system design for stability
improved stability radiometers
Aquarius prototype capabilities
Technologies -Basic thermal design & control -Radiometer system design for stability
Limited stability radiometers
Various capabilities
Technologies -Basic thermal control
Increasing Technical Capability
Current
Far Term
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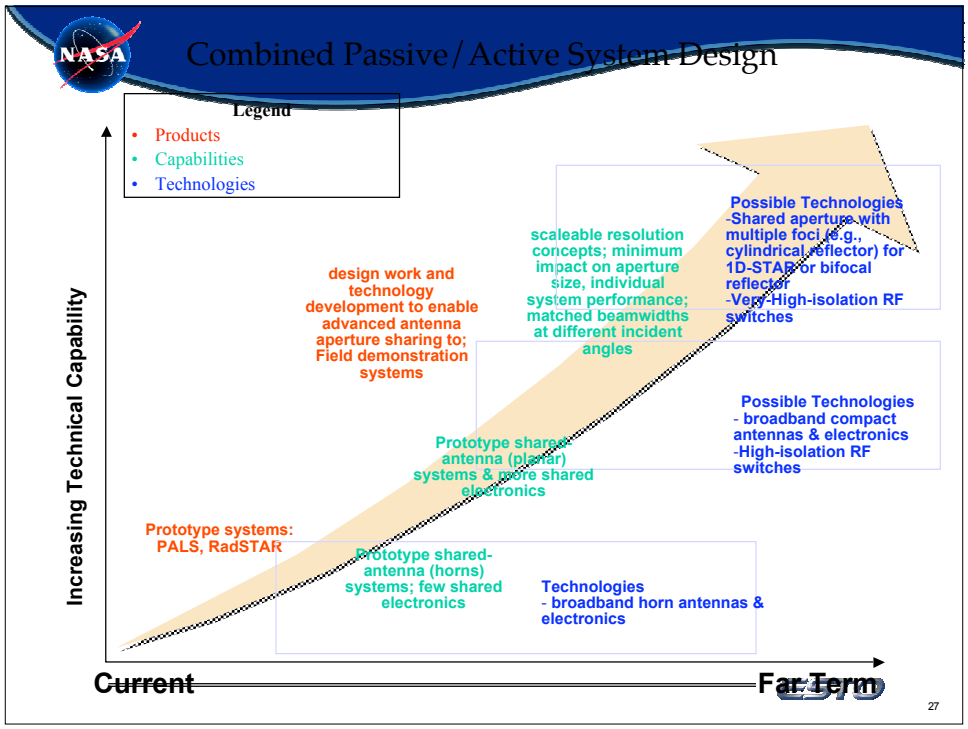
Combined Passive / Active System Design
Legend
• Products
• Capabilities
• Technologies
Increasing Technical Capability
Current
Far Term
Prototype systems: PALS, RadSTAR
design work and technology development to enable advanced antenna aperture sharing to; Field demonstration systems
Prototype shared-antenna (horns) systems; few shared electronics
scaleable resolution concepts; minimum impact on aperture size, individual system performance; matched beamwidths at different incident angles
Prototype shared-antenna (planar) systems & more shared electronics
Technologies
- broadband horn antennas & electronics
Possible Technologies
- broadband compact antennas & electronics
-High-isolation RF switches
Possible Technologies
-Shared aperture with multiple foci (e.g., cylindrical reflector) for 1D-STAR or bifocal reflector
-Very-High-isolation RF switches
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